ELSEVIER

Agricultural Economics 17 (1997) 277–288

AGRICULTURAL
ECONOMICS

Cap reform: modelling supply response subject to the land set-aside

V. Eldon Ball [a,*], Jean-Christophe Bureau [b], Kelly Eakin [c], Agapi Somwaru [d]

[a] *Natural Resources and Environment Division, Economic Research Service, U.S. Department of Agriculture, Washington, DC, USA*
[b] *Institut National de la Recherche Agronmique, Station d'Economie et Sociologie Rurales, Grignon, France*
[c] *L.R. Christensen and Associates, Madison, WI, USA*
[d] *Commercial Agriculture Division, Economic Research Service, U.S. Department of Agriculture, Washington, DC, USA*

Accepted 18 February 1997

Abstract

This paper uses duality theory to develop a model of European Community agriculture. The model is used to investigate the impact of the land set-aside provision of the recent package of reforms of the Common Agricultural Policy. We assume that producers chose output and variable input levels that maximize difference between revenue and variable cost. By including first-order conditions for the allocation of land across its uses, we impose that the observed allocations are profit-maximizing allocations. To overcome the problem of incorporating many outputs into an estimable production structure, we imposed a priori the restriction that the technology was weakly separable in major categories of outputs. With this restriction, it was possible to model production decisions in stages using consistent aggregates in the latter stages. © 1997 Elsevier Science B.V.

Keywords: Duality theory; Land set-aside; Common Agricultural Policy

1. Introduction

The European Community (EC) adopted a major reform of its Common Agricultural Policy (CAP) in May 1992. The reform package includes: (1) reduction of support prices, (2) introduction of corresponding compensatory payments and (3) introduction of new supply control measures.

The EC provides much of its support to farmers through minimum guaranteed prices. The package of reforms lowers support prices for cereals, beef and dairy. Guaranteed minimum prices for protein crops were ended, as were guaranteed prices for oilseeds, prior to CAP reform. Producers will be compensated for cereals, oilseeds and protein crop price reductions by direct payments, the latter based on historical yields and planted area. A set-aside requirement, initially set at 15% of the area planted to these crops, will apply to large producers wishing to receive compensatory payments. Although producers will be required to set aside a percentage of the land planted to cereals, oilseeds and protein crops, the allocation of land between these crops is unrestricted.

In this paper, we integrate the land set-aside requirement into a model of supply response. We begin by assuming that producers choose output and variable input levels that maximize the difference between revenue and variable cost. Family labor and total land area are treated as fixed inputs. We further assume that the observed land allocations between

* Corresponding author.

0169-5150/97/$17.00
PII S0169-5150(97)00026-1

cereals and oilseeds and protein crops are profit maximizing. Moreover, by including first-order conditions for the allocation of land across its uses, we impose that the observed land allocations are profit-maximizing allocations.

The first-order conditions imply long-run solutions to the land allocation equations. Including the profit-maximizing land allocation equations in the model of restricted behavior allows us to model unrestricted or long-run behavior. Long-run output supplies and input demands are obtained by evaluating the short-run response functions at the profit-maximizing land allocations. While the restricted profit function and the land allocation equations and the unrestricted or long-run profit function are equivalent representations of technology, the estimating equations differ. And by exploiting the comparative static properties of the restricted profit function, we can simultaneously capture restricted and unrestricted behavioral responses.

To estimate the model requires that we specify a functional form for the restricted profit function. The class of 'flexible' functional forms can, in principle, model very general production structures. However, their application to the many output case is hampered by the fact that the estimating equations are simple monotonic functions of prices or quantities which are often highly correlated. We reduce the multicollinearity problems at the cost of imposing a priori the restriction that the production structure is weakly separable in major categories of outputs. With this restriction, it is possible to model production decisions in stages, using consistent aggregates in the latter stages.

The organization of the paper is as follows. In Section 2, the theoretical model is discussed. The empirical model is presented in Section 3. We specify functional forms for the restricted profit and aggregator functions in Section 4. The estimation procedure is discussed in Section 5. The model is applied to panel data described in Section 6. Section 7 presents the empirical results. Section 8 concludes.

2. The theoretical model

Our starting point is a specification of the technical possibilities that firms face. These are summarized by the production possibilities set T that gives all feasible output and input combinations. At its most general, T may be expressed as an $(m+n)$-dimensional vector z that contains both outputs and inputs. Here, z represents the net output, or netput, vector. By convention, z_i is an output if it is positive and an input if it is negative. T is the set of all z combinations that are feasible given the technology. We assume that T is a nonempty, closed and convex subset of $\Re^{m+n}$.

2.1. The multioutput profit function

Let $q > 0$ denote the netput price vector, which producers take as given. Then the multiple output profit function which corresponds to T is defined as:

$$\pi(q) \equiv \max_z \{ q \cdot z : (z) \epsilon T \} \tag{1}$$

where $q \cdot z$ is the inner product $(\Sigma_i q_i z_i)$. The profit function $\pi(q)$ is positive linearly homogeneous and convex in q. If, in addition, $\pi(q)$ is differentiable, it satisfies Hotelling's lemma. That is:

$$z(q) = \nabla_q \pi(q) \tag{2}$$

where $z(q)$ is the solution vector to Eq. (1). Hence, we assume that $\pi(q)$ is twice continuously differentiable in all its arguments.

2.2. The restricted profit function

In what follows, the discussion is in terms of a netput vector which we continue to denote as z. However, in the current notation, z need not be an $(m+n)$-dimensional vector, and to emphasize this, we assume only that $z \in = \mathrm{R} = k$. We continue to represent the technology by the production possibilities set. However, we modify our earlier presentation by introducing the parameter vector θ; the interpretation of θ will be made clear in the discussion that follows. Assume that $\theta \in \mathrm{R}^2$. For notational convenience, we continue to use T to represent the production possibilities set. As before, $z_i > 0$ is an output, while $z_i < 0$ is an input. Also continue to use $q > 0$ to denote the netput price vector.

With these definitions, the restricted profit function is defined as:

$$\pi(q,\theta) \equiv \max_z \{ q \cdot z : (z,\theta) \in T \} \tag{3}$$

The restricted profit function $\pi(q,\theta)$ is positive linearly homogeneous and convex in q.

We now turn to the interpretation of the vector θ. Perhaps the most intuitive interpretation is that of a vector of outputs and inputs that are fixed in the short run. Thus, $\pi(q,\theta)$ is, in a sense, a short-run profit function. But, in fact, Eq. (3) generalizes the cost, revenue and profit functions. Let $q \equiv (p,w)$; that is, q is an $(m+n)$-dimensional vector of output and input prices. Define θ as an m-dimensional vector of fixed outputs and z as an n-dimensional vector of inputs. In this case, $z \leq 0$ and Eq. (3) is the negative of the cost function $c(y,w)$. Alternatively, suppose θ is an n-dimensional vector of fixed inputs and z is a vector of positive outputs. Eq. (3) is an obvious generalization of the revenue function $R(p,x)$. Finally, let $z \equiv (y,-x)$ and θ be a vector of parameters indexing the level of technology. Then $\pi(q,\theta)$ is a multioutput profit function admitting technical change.

This section concludes by noting that $\pi(q,\theta)$, if differentiable, satisfies a version of Hotelling's lemma. That is:

$$z(q,\theta) = \nabla_q \pi(q,\theta) \tag{4}$$

where $z(q,\theta)$ is the profit maximizing vector of net outputs.

2.3. Short-versus long-run profits

Let θ denote an n-dimensional vector of fixed inputs. Short-run total profits are defined as:

$$\pi^s(p,w,x) \equiv R(p,x) - w \cdot x \tag{5}$$

By definition of $R(p,x)$, short-run profits are maximized for any choice of x. Hence

$$\pi(p,w) \equiv \max_x \pi^s(p,w,x) \tag{6}$$

From Eq. (6), it follows that:

$$\pi(p,w) = \pi^s(p,x(p,w)) \tag{7}$$

where $x(p,w)$ is the solution to Eq. (6). Eq. (7) implies that the long-run profit function $\pi(p,w)$ is the upper envelope of the respective short-run profit functions. The functions coincide at the point where the fixed endowment vector is profit maximizing. Moreover, since the two curves are tangent:

$$\nabla_p \pi(p,w) = \nabla_p \pi^s(p,x(p,w)) \tag{8}$$

which by Hotelling's lemma implies that:

$$y(p,w) = y(p,x(p,w)) \tag{9}$$

That is, the long-run supply equals the corresponding short-run supply evaluated at the fixed input vector that maximizes long-run profits.

2.4. Comparative statics of output and input price changes

We now turn to a decomposition of the multioutput supply response. Differentiating Eq. (9) with respect to p and w yields:

$$\partial y_i(p,w)/\partial p_j = \partial y_i(p,x)/\partial p_j + \sum_{v=1}^{n} \partial y_i(p,x) /\partial x_v \partial x_v(p,w)/\partial p_j \tag{10}$$

$$\partial y_i(p,w)/\partial w_k = \sum_{v=1}^{n} \partial y_i(p,x) /\partial x_v \partial x_v(p,w)/\partial w_k \tag{11}$$

The comparative static responses can be decomposed into two separate effects: the substitution effect brought about by a change in relative output prices and the input scale effect. This latter effect represents the impact on supply of the change in input levels induced by a change in output price.

The supply response to a change in input price stems from a change in the input mix.

Thus far we have not exploited the convexity property of $\pi(p,w)$. By symmetry of $\nabla_{pw}\pi$ and Eq. (11):

$$\begin{aligned}\partial x_v(p,w)/\partial p_j &= -\partial y_j(p,w)/\partial w_v \\ &= -\sum_{r=1}^{n} \partial y_j(p,x)/\partial x_r \partial x_r(p,w)/\partial w_v\end{aligned} \tag{12}$$

Substituting this expression into Eq. (10) gives:

$$\begin{aligned}\partial y_i(p,w)/\partial p_j &= \partial y_i(p,x)/\partial p_j - \sum_{N=1}^{n} \sum_{r=1}^{n} \partial y_i(p,x) \\ &\quad /\partial x_v \partial x_r(p,w)/\partial w_v \partial y_j(p,x)/\partial x_r\end{aligned} \tag{13}$$

When $i=j$ in Eq. (13), one obtains the well-known Le Chatelier–Samuelson relationship:

$$\partial y_i(p,w)/\partial p_i \geq \partial y_i(p,x(p,w))/\partial p_i \geq 0 \quad (14)$$

This inequality follows because the second term on the right-hand side of Eq. (13) is a quadratic form in the positive semidefinte sub-Hessian $\nabla_{pp}\pi(p,w) = \nabla_{py}(p,w)$ when $_{i=j}$

2.5. Separability and multistage optimization

Finally, to avoid aggregating across outputs, we impose a priori the restriction that the production structure is weakly separable in major categories of outputs. Imposing weak separability in a subset of output prices, we can write the restricted profit function as:

$$\pi(q,\theta) = \pi(q_1(p_1,\dots,p_r),q_2,\dots,q_k,\theta) \quad (15)$$

where $q_1(p_1,\dots,p_r)$ is an appropriately chosen homogeneous aggregator function and q_1 is an aggregate price index for the separable group of outputs.

Weak separability of the profit function in a subset of output prices implies that the underlying technology is homothetically separable in the output quantities. A corresponding aggregate quantity index $z_1(y_1,\dots,y_r)$ exists and is homogeneous of degree one in its components.

Imposition of the separability restriction yields two important simplifying results. First, weak separability ensures consistent aggregation. Second, the existence of an aggregate that is homogeneous in its components implies a two-stage optimization procedure: choose the optimal mix of commodities within the aggregate and then choose the level of the aggregate. The former result justifies the specification of a model in the components alone, while the latter result justifies the specification of a model in the aggregates alone.

3. The empirical model

Reform of the CAP reduces agricultural support prices. Producers of cereals, oilseeds and protein crops are compensated for reductions in support prices by direct payments, the latter based on historical yields and planted area. This payment is contingent upon idling a proportion of the land area planted to these crops. However, the allocation of land between cereals, oilseeds and protein crops is unrestricted. In this section, we adapt the restricted profit function model developed in Section 2 to investigate the effects of the set-aside policy.

3.1. The unrestricted model

As before, let z denote the net output vector. We continue to use q to denote the vector of output and variable input prices. Finally, define θ as total land area L in agriculture. T is now defined as the set of all feasible (z,L) combinations. In this specification, land has the characteristic of being 'fixed in acquisition' but 'variable in use'. [1]

Given exogenous prices, the restricted profit function is defined as:

$$\pi(q,L) \equiv \max_z\{q\cdot z:(z,L)\in T\} \quad (16)$$

And applying Hotelling's lemma:

$$z(q,L) = \nabla_q\pi(q,L) \quad (17)$$

We refer to the system of Eqs. (16) and (17) as the unrestricted model because the allocation of land is unrestricted. The unrestricted model is appropriate to investigate producer behavior conditional on the fixed endowment of land. However, with this model, we cannot investigate the effects of the set-aside policy.

3.2. The restricted model

We now develop an alternative model, the restricted model, which allows us to investigate the effects of the land set-aside. Our restricted model results from altering the unrestricted model to include variables that describe the allocation of land between production activities. To focus attention on

[1] This distinction was originally made by Machlup (1952) and recently brought to our attention by Larson (1991).

the proposed land set aside, we narrow the allocation of land to three use: (1) production of cereals, (2) production of oilseeds and protein crops and (3) all other production activities. The technology is described by the set of feasible combinations (z,L,a_1,a_2), where a_1 and a_2 denote the proportion of land allocated to cereals and oilseeds and protein crops, respectively.

Assuming profit maximizing behavior, the restricted model can be written:

$$\pi(q,L,a_1,a_2) \equiv \max_z (q \cdot z:(z,L,a_1,a_2) \in T) \tag{18}$$

and

$$z(q,L,a_1,a_2) = \nabla_q \pi(q,L,a_1,a_2) \tag{19}$$

The restricted model would be appropriate if there were no choice on land allocation; that is, land was 'fixed in acquisition' and 'fixed in use.' However, during the period covered by the data, there were no restrictions on land allocation. Furthermore, even under CAP reform, there is still some choice in land allocation. Thus, the restricted model given by Eqs. (18) and (19) above is incomplete for our purposes.

3.3. The indirect unrestricted model

To complete our model, we recognize that, when there are no acreage restrictions, the profit maximizing producer will allocate the fixed land area across the different production uses such that:

$$\nabla_a \pi(q,L,a_1,a_2) = 0 \tag{20}$$

These first-order conditions imply optimal land allocations equations:

$$a_i^* = a_i(q,L), i = 1,2 \tag{21}$$

Incorporating the first-order conditions into the restricted model yields the indirect unrestricted model; that is, the restricted profit function evaluated at the optimal land allocations:

$$\pi(q,L) = \pi(q,L,a_1^*,a_2^*) \tag{22}$$

and

$$z(q,L) = \nabla_q \pi(q,L,a_1^*,a_2^*) \tag{23}$$

The restricted profit function given by Eq. (18) is conditional on the allocation of land across the different crops. If the allocation of land is optimal across the three crop categories then restricted profits equal unrestricted profits. Thus, incorporating the optimal land allocation equations, a_1^* and a_2^*, in the restricted profit function results in a representation of the unrestricted profit function, as indicated by Eq. (22).

The systems of Eqs. (16), (17), (22) and (23) are equivalent representations of technology. However, using Eqs. (22) and (23) as our empirical model, we can investigate the effects of CAP reform. That is, we can model the set-aside policy even though our data are for a period when land allocation was unrestricted.

4. Functional forms for profit and aggregator functions

4.1. The normalized restricted profit function

The restricted profit function is approximated by the normalized restricted profit function (Diewert and Ostensoe, 1988). Define θ as an l-dimensional vector of outputs and inputs that are fixed in the short run. Then $\pi(q,\theta)$ is written:

$$\begin{aligned}\pi(q,\theta) \equiv{}& 1/2\left(\sum_{i=1}^{l} \alpha_i \theta_i\right)\Big(\sum_{i=2}^{k}\sum_{j=2}^{k} A_{ij} q_i q_j / q_1 \\ &+ 1/2\left(\sum_{i=1}^{k} \beta_i q_i\right)\left(\sum_{i=2}^{l}\sum_{j=2}^{l} B_{ij}\theta_i\theta_j/\theta_1\right) \\ &+ \sum_{i=1}^{k}\sum_{j=1}^{l} C_{ij} q_i \theta_j \\ &+ \sum_{i=1}^{k}\sum_{j=1}^{s} (C_i + \lambda_{ij} D_j) q_i \\ &+ \left(\sum_{i=1}^{k} \beta_i q_i\right)\left(\sum_{j=2}^{l} B_j \theta_j/\theta_1\right) \\ &+ 1/2\left(\sum_{i=1}^{k} B_0\, \beta_i q_i/\theta_1\right)\end{aligned} \tag{24}$$

where α and β are prespecified parameter vectors, $A_{ij} = A_{ji}$, $B_{ij} = B_{ji}$, C_{ij}, λ_{ij}, C_i, and B_0 are parameters that must be estimated. The variable D_j is a country specific dummy variable taking on a value of one for observations on country j and zero otherwise.

Note that the normalized restricted profit function π defined by Eq. (24) is linearly homogeneous in prices q. In order for $\pi(q,\theta)$ to be a convex function of q, it is necessary and sufficient that the matrix A be positive definite. Lau (1978) has shown that every positive definite matrix has a Cholesky factorization. The matrix A can thus be written in terms of the Cholesky decomposition as $A = LDL'$ where L is a unit lower triangular matrix ($L_{ii} = 1$; $L_{ij} = 0$, $j > i$) and D is a diagonal matrix with typical element D_{ii} referred to as a Cholesky value. Lau demonstrates that if the matrix A is to be positive definite the $D_{ii} > 0$. Thus imposing positivity on the D_{ii} is sufficient to impose convexity on $\pi(q,\theta)$.

Rather than reparameterizing the function to be estimated in terms of the Cholesky parameters and then restrict the D_{ii}, we express the Cholesky decomposition in terms of the parameters A_{ij} and restrict a function of these parameters equivalent to the D_{ii}. That is:

$$D_{ii} = g(q,\theta,\delta) > 0, i = 1,\dots,k \tag{25}$$

where δ is the system parameter vector.

Applying Hotelling's lemma yields output supply and input demand functions:

$$\begin{aligned} z_1(q,\theta) = & -1/2\left(\sum_{i=1}^{l} \alpha_i\theta_i\right)\left(\sum_{i=2}^{k}\sum_{j=2}^{k} A_{ij}q_iq_j/q_1^2\right) \\ & + 1/2\beta_1\left(\sum_{i=2}^{l}\sum_{j=2}^{l} B_{ij}\theta_i\theta_j/\theta_1\right) \\ & + \sum_{j=1}^{l} C_{1j}\theta_j + \sum_{j=1}^{s}(C_1 + \lambda_{1j})D_j \\ & + \beta_1\left(\sum_{j=2}^{l} B_j\theta_j/\theta_1\right) \\ & + 1/2B_0\,\beta_1/\theta_1 \end{aligned} \tag{26}$$

and

$$\begin{aligned} z_i(q,\theta) = & \left(\sum_{j=1}^{l}\alpha_j\theta_j\right)\left(\sum_{j=2}^{k} A_{ij}q_j/q_1\right) \\ & + 1/2\beta_i\left(\sum_{h=2}^{l}\sum_{j=2}^{l} B_{hj}\theta_h\theta_j/\theta_1\right) \\ & + \sum_{j=1}^{l} C_{ij}\theta_j + \sum_{j=1}^{s}(C_i + \lambda_{ij})D_j \\ & + \beta_i\left(\sum_{j=2}^{l} B_j\theta_j/\theta_1\right) \\ & + 1/2B_o\,\beta_i/\theta_1, i = 2,\dots,k \end{aligned} \tag{27}$$

The restricted profit function (Eq. (24)) and the output supply and input demand Eqs. (26) and (27) represent a system of $k+1$ equations, of which any k are independent. Consequently, we omit the profit function from the system of equations to be estimated.

Let (L,a_1,a_2), as previously defined, be elements of the vector θ. Setting $\partial\pi(\mathrm{q},\theta)/\partial\theta_2$ and $\partial\pi(\mathrm{q},\theta)/\partial\theta_3$ equal to zero and rearranging terms yields:

$$\begin{aligned} \theta_2 = & -1/B_{22} * \left(\left(\theta_1/\left(\sum_{i=1}^{k}\beta_iq_i\right)\right)1/2\alpha_2\right. \\ & \times\left(\sum_{i=2}^{k}\sum_{j=2}^{k} A_{ij}q_iq_j/q_1\right) \\ & + \left(\sum_{j\neq 2}^{l} B_{2j}\theta_j\right) \\ & \left. + \left(\theta_1/\left(\sum_{i=1}^{k}\beta_iq_i\right)\right)\left(\sum_{i=1}^{k} C_{i2}q_i\right) + B_2\right) \end{aligned} \tag{28}$$

and

$$\begin{aligned} \theta_3 = & -1/B_{33} * \left(\left(\theta_1/\left(\sum_{i=1}^{k}\beta_iq_i\right)\right)1/2\alpha_3\right. \\ & \times\left(\sum_{i=2}^{k}\sum_{j=2}^{k} A_{ij}q_iq_j/q_1\right) \\ & + \left(\sum_{j\neq 3}^{l} B_{3j}\theta_j\right) \\ & \left. + \left(\theta_1/\sum_{i=1}^{k}\beta_iq_i\right)\right)\left(\sum_{i=1}^{k} C_{i3}q_i\right) + B_3) \end{aligned} \tag{29}$$

The system of Eqs. (26) and (27) is estimated subject to the land allocation Eqs. (28) and (29) and the theoretical curvature restriction (Eq. (25)).

4.2. The aggregator function

Since q_1 in Eq. (15) is the price per unit of the output aggregate, it is also unit revenue to the optimizing agent. This revenue can be represented by an arbitrary unit revenue (alternatively, aggregator) function similar to Eq. (24):

$$R(p)/z_1 = 1/2 \sum_{i=2}^{r} \sum_{j=2}^{r} A_{ij} p_i p_j / p_1 + \sum_{i=1}^{r} C_i p_i \tag{30}$$

where z_1 is the output aggregate.

Revenue maximizing behavior implies that the supply functions for the components, expressed as output shares, take the form:

$$y_1/z_1 = -1/2 \sum_{i=2}^{r} \sum_{j=2}^{r} A_{ij} p_i p_j / p_1^2 + C_1 \tag{31}$$

and

$$y_i/z_1 = \sum_{j=2}^{r} A_{ij} p_j / p_1 + C_i, i = 2,\dots,r \tag{32}$$

Estimation of the complete model is accomplished via the following two-stage procedure.

(1) Estimate the system of Eqs. (31) and (32) subject to the constraints from theory. This provides an estimate of the quantities supplied and price elasticities of the commodities that comprise the aggregate, the level of the aggregate output z_1 held constant. In addition, by substituting the parameters estimates into Eq. (30) we obtain an estimate of the aggregate price index. This estimate serves as an instrumental variable in the second stage.

(2) Estimate the system of Eqs. (26) and (27), replacing the aggregate price index q_1 by its instrumental variable $\tilde{q}_1$.

5. Estimation

The econometric technique employed in this paper is described in Ball (1988) and is discussed only briefly here. The system of equations to be estimated can be written:

$$z_t - f(q_t, \theta_t | \delta) = \epsilon_t \tag{33}$$

where z_t is the vector of jointly dependent variables, q_t and θ_t are vectors of exogenous variables, δ is the system parameter vector and ϵ_t is an error vector. Assuming that the errors $(\epsilon_{1t},\dots,\epsilon_{kt})'$ are temporally independent, each with mean zero, the same distribution and positive definite error variance-covariance matrix Σ, the Aitken-type estimator δ is obtained by minimizing:

$$S(\delta) = 1/T \sum_{t=1}^{T} (z_t - f_t)' (\tilde{\Sigma} \otimes I)^{-1} (z_t - f_t) \tag{34}$$

Eq. (34) is minimized with respect to δ given a prior consistent estimate of . Using $\tilde{\delta}$, a new estimate of Σ is obtained based on the inner product of the estimated residuals. The estimates are iterated until the coefficient vector $\tilde{\delta}$ and the covariance matrix $\tilde{\Sigma}$ stabilize. It is well known (Madansky, 1966) that such iteration does not improve the asymptotic variance of the estimator. However, when estimating a system of equations with constraints across one of the endogenous variables, such iteration results in estimates that are invariant to the equation deleted under the assumed error structure (Berndt and Savin, 1975).

The estimation procedure must permit imposition of the first-order conditions for the allocation of land and the theoretical curvature restrictions. This procedure is characterized by the nonlinear constrained optimization problem:

$$\min_\delta S(\delta) = 1/T \sum_{t=1}^{T} (z_t - f_t)' (\tilde{\Sigma} \otimes I)^{-1} (z_t - f_t) \tag{35}$$

subject to:

$$h_t^i(q_t, \theta_t, \delta) = \phi_i,\ i = 1,2$$
$$g_t^i(q_t, \theta_t, \delta) > \psi_i,\ i = 1,\dots,k$$

where ${}^{hi}(\cdot)$ and $g_i(\cdot)$ are the land allocation equations and curvature restrictions, respectively, and ϕ_i and ψ_i are constraint values. The objective function (Eq. (35)) is minimized subject to the constraint set using the Generalized Algebraic Modeling System (GAMS 2.25) (Brooke et al., 1993).

We modify the Aitken procedure by imposing the equality and inequality constraints in the first stage, replacing $(\tilde{\Sigma} \otimes I)^{-1}$ in Eq. (35) with the identity matrix, and then solving for $\tilde{\delta}$. Using $\tilde{\delta}$, a new estimate of $_{\Sigma}$ is obtained based on the inner product of residuals. The problem in Eq. (35) is then solved with $(\tilde{\Sigma} \otimes I)^{-1}$ employed as the weighting matrix. Finally, we iterate over steps one and two until the estimated parameter vector $\tilde{\delta}$ and error variance–covariance matrix $\tilde{\Sigma}$ stabilize.

6. The data

We require data on relative prices of outputs and inputs in each country in the analysis. [2] The traditional approach of using exchange rates to estimate relative prices is well known to be unsatisfactory. To determine relative price levels, we compute purchasing power parities for different currencies based on observations of prices of comparable goods.

The purchasing power parities are obtained in two-separate steps. First, for 1985, we calculate bilateral parities between each national currency and some reference currency as Fisher ideal price indexes. Diewert (1976) has shown that the Fisher index is exact for a homogeneous quadratic aggregator function.

If the number of countries I in the analysis exceeds two, the application of the Fisher index to the $I(I-1)/2$ possible pairs of countries yields a matrix of bilateral parities that does not satisfy the transitivity condition. To overcome this problem, we apply the multilateral Eltetö and Köves (1964) or Szulc (1964) method which defines the parities between each pair of currencies as the geometric mean of I ratios of the bilateral Fisher indexes. It can be shown that the multilateral EKS index achieves transitivity while minimizing the deviations from the bilateral Fisher indexes.

Next, we construct intertemporal Fisher indexes of prices and quantities in each country. Since the purchasing power parities are calculated for only one year, we use 1985 as the base year and calculate parities for the remaining years by chain-linking them to 1985. These spatial deflators are used to convert national value aggregates into a common currency unit.

The dimensions of the purchasing power parities are the same as the nominal exchange rate. However, the parities reflect the prices of the outputs and inputs in each country relative to the numeraire country. To translate the parities into relative prices expressed in the reference currency, we divide the parity by the nominal exchange rate.

Estimates of capital input in EC agriculture have been compiled by Ball et al. (1993). Capital stocks are divided into structures and machinery and transportation vehicles. We aggregate across the different asset types using capital rental prices. To obtain the purchasing power parity for capital input, we multiply the purchasing power parity for investment goods by the ratio of the rental prices for capital inputs.

7. Empirical results

The aggregate model identifies seven outputs including cereals, sugar beets, oilseeds and protein crops, other crops, fluid milk and two categories of livestock production. Variable inputs include feedstuffs, other purchased inputs and service flows from the stock of capital. We have attempted to incorporate several important characteristics of EC agriculture in the empirical model. These characteristics include a binding quota on milk production and a large component of household labor. Therefore, the supply of milk, [3] household labor services and the total land area were assumed fixed in the short run.

A number of the outputs and inputs in the empirical model are aggregates. In the first stage of our multistage model, we estimate aggregator functions for cereals and oilseeds and protein crops. We now turn to a discussion of these results.

[2] We compile data for Germany, France, Italy, The Netherlands, Belgium–Luxembourg Economic Union, the United Kingdom, Ireland, Denmark and Greece.

[3] The milk quota was introduced in 1985. Prior to 1985, the supply of milk must be viewed as being endogenous. Hence, instrumental variables were used in estimation.

7.1. The aggregator functions

The first-stage model provides estimates of the parameters of the aggregator functions and the aggregate price indexes for the separable groups of commodities. The parameter estimates are country specific and, thus, too numerous to report here. However, the estimates and their asymptotic standard errors are available from the authors upon request.

To focus attention on the price responsiveness of individual cereals and oilseeds and protein crops, we report in Tables 1 and 2 estimates of the own- and cross-price elasticities of supply. These elasticities are calculated as:

$$\epsilon_{11} = \sum_{i=2}^{r} \sum_{j=2}^{r} A_{ij} p_i p_j / p_1^2 y_1 \tag{36}$$

$$\epsilon_{1j} = - \sum_{i=2}^{r} A_{ij} p_j / p_1^2 y_1, j = 2, \ldots, r \tag{37}$$

$$\epsilon_{i1} = - \sum_{j=1}^{r} A_{ij} p_j / p_1 y_i, i = 2, \ldots, r \tag{38}$$

$$\epsilon_{ij} = A_{ij} p_j / p_1 y_i, i, j = 2, \ldots, r \tag{39}$$

Eqs. (36)–(39) are derived under the assumption that the levels of output of cereals and oilseeds and protein crops are held constant; that is, they are measurements along the production possibilities frontier. We present these results with the aggregates held constant in order to emphasize the output substitution possibilities. However, the results are valid when the aggregate levels are variable and depend only on the assumption that the first-stage model is linear homogeneous in the level of aggregate output.

There is a different elasticity for each year and for each country. We present elasticities calculated at the mean values of the exogenous variables for France as representative. The results for the remaining countries are available from the authors upon request.

Table 1
Price elasticities: aggregate cereals constant, calculated at mean values for France

	Wheat	Maize	Barley	Other cereals
Wheat	0.023	−0.002	−0.007	−0.015
Maize	−0.001	0.037	−0.025	−0.010
Barley	−0.031	−0.037	0.083	−0.024
Other cereals	−0.332	−0.096	−0.164	0.592

Table 2
Price elasticities: aggregate oilseeds and protein crops constant, calculated at mean values for France

	Rapeseed	Sunflower seed	Soybeans	Protein crop
Rapeseed	0.142	−0.046	−0.034	−0.062
Sunflower seed	−0.087	0.088	0.021	−0.022
Soybeans	−0.053	0.175	0.135	0.223
Protein crops	−0.144	−0.027	0.033	0.138

First, note that the results are consistent with the postulates of revenue maximizing behavior as the aggregator functions for cereals and oilseeds and protein crops were estimated subject to restrictions from theory.

There appears to be limited price responsiveness among individual cereals. In all cases, supply is price inelastic. Moreover, the potential for substitution along the production possibilities frontier is quite limited. Individual oilseeds and protein crops are only slightly more responsive to price changes.

We now turn to a discussion of the results of the second-stage of our multistage model: the model used to determine the supply response of aggregate cereals and oilseeds and protein crops.

7.2. The aggregate model

As before, we present summary measures of price responsiveness. Table 3 presents restricted or short-run elasticities calculated at the mean values of the exogenous variables for France. The short-run elasticities, given by Eqs. (40)–(43), are conditional on the observed land allocations:

$$E_{11}^{s} = \left(\sum_{i=1}^{l} \alpha_i \theta_i \right) \left(\sum_{i=2}^{k} \sum_{j=2}^{k} A_{ij} q_i q_j / q_1^2 z_1 \right) \tag{40}$$

$$E_{1j}^{s} = - \left(\sum_{i=1}^{l} \alpha_i z_i \right) \left(\sum_{i=2}^{k} A_{ij} q_j / q_1^2 z_1 \right), j = 2, \ldots, k \tag{41}$$

$$E_{i1}^{s} = - \left(\sum_{i=1}^{l} \alpha_i \theta_i \right) \left(\sum_{j=2}^{k} A_{ij} q_j / q_1 z_1 \right), i = 2, \ldots, k \tag{42}$$

$$E_{ij}^{s} = \left(\sum_{i=1}^{l} \alpha_i \theta_i \right) \left(A_{ij} q_j / q_1 z_i \right), i, j = 2, \ldots, k \tag{43}$$

Table 3
Price elasticities: land use constant, calculated at mean values for France

	Cereals	Sugar	Oilseeds	Other crops	Monogastrics	Polygastrics	Feed	Other purchased	Capital
Cereals	0.036	−0.009	0.006	−0.007	0.009	−0.029	−0.034	0.032	−0.005
Sugar	−0.061	0.234	−0.141	0.038	0.046	0.117	−0.165	0.081	−0.057
Oilseeds	0.036	−0.133	0.080	−0.022	0.026	−0.068	0.090	−0.043	0.033
Other crops	−0.005	0.004	−0.002	0.002	−0.001	0.004	0.004	−0.004	−0.001
Monogastrics	0.012	−0.009	0.006	−0.003	0.012	−0.021	0.016	−0.004	−0.009
Polygastrics	−0.026	0.016	−0.010	0.006	−0.014	0.088	−0.022	−0.025	−0.013
Feedstuffs	0.044	0.033	−0.019	−0.008	−0.016	0.032	−0.171	0.102	0.003
Other purchased	−0.020	−0.008	0.004	0.004	0.002	0.017	0.048	−0.041	−0.006
Capital	0.007	0.012	−0.007	0.002	0.009	0.019	0.003	−0.014	−0.031

All aggregate outputs (factors of production) have own-price elasticities which are in the inelastic range. The own-price elasticities of supply of cereals and oilseeds and protein crops are 0.036 and 0.080, respectively. When compared with the own-price elasticities of the components, we find that the components are more price responsive. This is because of the substitution possibilities (though limited) between individual cereals and oilseeds and protein crops.

Of particular interest is the estimated supply response of sugar crops. The production of sugar beets in the European Community is subject to a quota. Farmers may produce 'off-quota' sugar (known as 'C' sugar), but the price of 'C' sugar is not supported. Since there are no effective constraints on production, we treated the supply of sugar crops as endogenous. The marginal price of sugar in each country, whether 'A', 'B' or 'C' sugar, was used as the explanatory variable. Two exceptions were Italy and the Netherlands where the prices of sugar are pooled and the producer receives an average. The estimated supply response appears to support this specification.

The results presented in Table 3 do not allow the land allocations to adjust to changes in relative prices. Unrestricted or long-run elasticities are calculated using the comparative static results in Eq. (13). These estimates are reported in Table 4. Note that the results are consistent with the Le Chatelier–Samuelson relationship. Supply is more responsive when measured at the profit maximizing land allocations. Still, the estimated supply schedules are quite inelastic.

We conclude this section by reporting in Tables 5 and 6 the estimated cereal- and oilseed-component price elasticities with aggregate cereals and oilseeds and protein crops variable. The results reported in Tables 1 and 2 were calculated holding the aggregates constant in order to highlight the substitution

Table 4
Price elasticities: land use variable, calculated at mean values for France

	Cereals	Sugar	Oilseeds	Other crops	Monogastrics	Polygastrics	Feed	Other purchased	Capital
Cereals	0.059	0.002	0.017	−0.031	0.046	−0.078	−0.057	0.041	−0.002
Sugar	0.029	0.277	−0.097	−0.058	0.097	−0.075	−0.256	0.118	−0.046
Oilseeds	0.110	−0.105	0.112	−0.098	0.128	−0.209	0.015	−0.002	0.040
Other crops	−0.019	−0.008	−0.012	0.018	−0.034	0.045	0.018	−0.003	−0.004
Monogastrics	0.064	0.022	0.033	−0.059	0.106	−0.144	−0.036	0.010	−0.002
Polygastrics	−0.070	−0.017	−0.036	0.055	−0.108	0.206	0.022	−0.027	−0.021
Feedstuffs	0.070	0.054	−0.003	−0.038	0.043	−0.041	−0.196	0.100	0.008
Other purchased	−0.023	−0.007	0.004	0.006	0.002	0.018	0.051	−0.046	−0.006
Capital	0.001	0.013	−0.008	0.007	0.008	0.023	0.008	−0.021	−0.031

Table 5
Price elasticities: aggregate cereals variable, calculated at mean values for France

	Wheat	Maize	Barley	Other cereals
Wheat	0.056	0.013	0.003	−0.014
Maize	0.032	0.052	−0.015	−0.009
Barley	0.002	−0.022	0.093	−0.023
Other cereals	−0.299	−0.081	−0.153	0.593

Table 6
Price elasticities: aggregate oilseeds and protein crops variable, calculated at mean values for France

	Rapeseed	Sunflower seed	Soybeans	Protein crops
Rapeseed	0.199	−0.015	−0.031	−0.037
Sunflower	−0.030	0.118	0.025	−50.003
Soybeans	0.004	0.205	0.138	0.248
Protein crops	0.087	0.004	0.036	0.163

possibilities. However, to calculate the total effect of a price change we need to recognize that a change in the price of an individual cereal or oilseed also changes the aggregate price index. This results in substitution between aggregate cereals and oilseeds and protein crops and other aggregates which affects the supply of the components. It can be shown that the total effect of a price change is given by:

$$\epsilon_{ij} = \epsilon_{ij}^{z} + R_j E_{zz}, \quad (44)$$

where ϵ_{ij} is elasticity of supply of y_i with respect to p_j, ϵ_{ij}^{z} is this elasticity with the aggregate output level constant (from Tables 1 and 2), R_j is the revenue share of the jth component and E_{zz} is the own-price elasticity of the output aggregate.

8. Summary and conclusions

In this paper, we use duality theory to develop a model of European Community agriculture. This model is used to investigate the impact of the land set-aside provision of the recent package of reforms of the Common Agricultural Policy.

The reforms reduce agricultural support prices. Producers of cereals, oilseeds and protein crops are compensated for reductions in support prices by direct payments. This payment is contingent upon idling a proportion of the land area planted to these crops. However, the allocations of land between these crops is unrestricted.

We assumed that the observed land allocations were profit maximizing allocations. Moreover, the land-allocations equations implied by first-order conditions were introduced as constraints in the model, as were the theoretical curvature restrictions. To deal with the problem of incorporating many outputs into an estimable production structure, we imposed a priori the restriction that the technology was weakly separable in major categories of outputs. With this restriction, it was possible to model production decisions in stages using consistent aggregates in the latter stages.

Aggregator functions were estimated for cereals and oilseeds and protein crops in the first stage. This provided estimates of the elasticities of supply of the components, the level of aggregate cereals and oilseeds and protein crops held constant. In all cases, supply was price inelastic. Moreover, the potential for substitution appears to be quite limited. All of the output aggregates exhibited an inelastic supply response, even when calculated at the profit maximizing land allocations.

References

Ball, V.E., 1988. Modeling supply response in a multiproduct framework. Am. J. Agric. Econ. 70, 813–825.

Ball, V.E., Bureau, J.C., Butault, J.P., Witzke, H.P., 1993. The stock of capital in European community agriculture. European Rev. Agric. Econ. 20, 437–450.

Berndt, E.R., Savin, N.E., 1975. Estimation and hypothesis testing in singular equation systems with autoregressive disturbances. Econometrica 43, 937–957.

Brooke, A., Kendrick, D., Meeraus, A., 1993. GAMS 2.25 for SUN 4/SPARC, Users' Guide. GAMS Development, Washington, DC.

Diewert, W.E., 1976. Exact and superlative index numbers. J. Econometrics 4, 115–145.

Diewert, W.E., Ostensoe, L., 1988. Flexible functional forms for profit functions and global curvature conditions. In: Barnett, W., Berndt, E., White, H. (Eds.), Dynamic Econometric Modeling. Cambridge Univ. Press, Cambridge.

Eltetö, O., Köves, P., 1964. On a problem of index number computation relating to international comparisons. Szatistikai Szemle 48, 507–518.

Larson, B., 1991. A dilemma in the theory of short-run production and cost. Southern Econ. J. 57, 465–474.

Lau, L.J., 1978. Testing and imposing monotonicity, convexity and quasi-convexity constraints. In: McFadden, D., Fuss, M. (Eds.), Production Economics: A dual approach to theory and applications. North-Holland, Amsterdam.

Machlup, F., 1952. The Economics of Sellers' Competition: Model Analysis of Sellers' Contract. Johns Hopkins Univer. Press, Baltimore.

Madansky, A., 1966. On the efficiency of three-stage least squares estimation. Econometrica 34, 851–861.

Szulc, B., 1964. Indices for multiregional comparisons. Przeglad Statystyczny 3, 239–254.